Children's National Medical Center

A Pediatric CIREN Center

CIREN Program Report

Children's National Medical Center (CNMC) is one of the frontline advanced scientific resources for understanding the significance and consequences of serious motor vehicle crash injuries in children. CNMC has been participating in government-funded crash reconstruction research since 1991. The detailed study of 286 children involved in motor vehicle crashes has resulted in the prevention, and the detection, diagnosis, and treatment of serious injuries. The following chapter outlines our research including past successes and future goals.

The Value of CIREN Research – Improving Diagnosis and Treatment of Children Injured in Crashes

Management of the injured pediatric crash victim requires immediate stabilization of the airway and restoration of circulation, followed by specific interventions directed at life-threatening injuries. However, the proper diagnosis of internal injuries despite a focused, accurate history, thorough physical exam, and excellent clinical judgment is extremely difficult even for the most experienced physicians.

Given the unique anatomy and physiology of children, diagnosis of injury is a challenge. Children have efficient compensatory mechanisms for volume loss; consequently, initial vital signs may be within normal limits though blood loss is present from internal injury. In addition, the decision to obtain radiographs is often based on external evidence of trauma, but internal injuries in children frequently occur without such external evidence. Moreover, abnormalities are not always evident on initial radiographs and findings may be non-specific because interpretation of radiographs is complicated by a large number of anatomical and physiological variations normal to child development.

Significant morbidity and mortality occurs in young children who are victims of crash-related injury, because the indications of internal injury in the pediatric patient are often so subtle that diagnosis is delayed, or worse yet, missed completely. For example, determination of the stability of the cervical spine in children can be particularly problematic; pre-vertebral soft tissues often mimic edema on radiographs, incompletely ossified vertebral bodies of the cervical spine result in anterior wedging mimicking C2-C3 compression fractures, and ligamentous laxity results in a widened predental space. Similarly, detection of intra-abdominal injury is complicated by the limitations of plain radiographic evaluation and by a paucity of specific findings. Diagnosis of thoracic injury is also difficult because immature skeletal structures have greater compliance, and, unlike adults, significant abdominal and pelvic visceral injuries in children usually occur in the absence of fractures.

CNMC has been recognized throughout the country as a premier level 1 pediatric trauma center. How did we establish this reputation? How are our physicians able to detect occult injuries so quickly? Why do we search diligently for internal injury based solely on mild-to-moderate localized tenderness during palpation or percussion? What prompts our surgeons to obtain an abdominal computed tomography (CT) scan on a hemodynamically stable child with normal initial radiographs and an unremarkable physical examination ultimately resulting in the identification of a life-threatening bowel injury? In other institutions, abdominal CT scans play a pivotal role in triaging and managing pediatric trauma victims with suspected intra-abdominal injury. Why do our radiologists often encourage exploratory laparotomy when abdominal CT scans reveal subtle and non-specific findings such as trace amounts of peritoneal fluid, or the smallest amount of mucosal edema? What pieces of information increase our index of suspicion for injury? We know that it is not feasible to perform plain radiographs, flexion/extension radiographs, CT scans, or

MRI images on every child involved in a motor vehicle crash. So why is it that we perform seemingly unnecessary procedures on children and “just happen” to find serious injuries requiring treatment?

The common answer to all these questions is that our institution has an integrated, multi-disciplinary approach to the study of crash-related injury in children – CIREN. This research has helped us do a better job of diagnosing and treating injuries in the pediatric crash victim. In general, diagnostic and treatment procedures are performed based solely on clinical indications of injury. And if those clinical indications fail to exist, a conservative “wait and watch” approach often is the only treatment method implemented. Few physicians understand the importance of elucidating the specific mechanism of injury and most fail to obtain valuable pre-hospital predictors of injury such as type of restraint used (automatic shoulder belt only, lap belt only, forward-facing car seat) and direction of impact (frontal, side, rear). The CIREN research conducted at our institution over the past 10 years has resulted in dramatic improvements in our approach to caring for the pediatric trauma patient. When combined with clinical and physical signs and symptoms, elucidation of the mechanism of injury provides our clinicians with a compass in the search for occult injuries. CIREN research allows us to go beyond standard practices to do a better job saving the lives of children. More importantly, the CIREN project enables us to share and disseminate our knowledge nationally and internationally, and to many different disciplines. It is impossible to make such progress in preventing crash-related death and disability without such a multidisciplinary research approach.

Seatbelts

CIREN data enables NHTSA to monitor changing injury patterns associated with current restraint systems. In the early 1990’s, our CIREN center was instrumental in contributing to the literature on seatbelt syndrome in children: lumbar spine fracture or subluxation, abdominal organ injury, perforation of intestinal viscera, and a belt-shaped ecchymosis on the abdomen pattern the seatbelt syndrome.

CIREN data revealed that young children restrained by seatbelts consistently sustained these injuries when involved in frontal crashes. By combining detailed medical and crash data, we were able to elucidate the specific occupant kinematics resulting in these injuries. In addition, we have become more skilled in identifying risk factors for internal injury. The combination of a history of a frontal impact crash for children restrained in 2 or 3 point seatbelts, abdominal pain or tenderness, and belt-shaped abdominal ecchymosis is highly suggestive of intra-abdominal injury and requires prompt, aggressive surgical work-up. Lateral spine x-rays and laparotomy based on CT findings and physical examination result in a more accurate diagnosis and a subsequent decrease in morbidity and mortality. This is one of the examples where CIREN research has assisted us in identifying seatbelt syndrome in children earlier in their presentation and allowed us to put into motion a course of treatment that might have otherwise been delayed or not implemented at all.

Child Restraint Systems

Many recent changes have been made to restraints and to the federal motor vehicle safety standards that govern them, but little is known about the performance of these technologies in protecting children during real-life crash situations. As technology changes, continued monitoring of restraint performance is needed, especially for children whose anatomy, stature, and physiology make their risk of injury very different than those of their adult counterparts.

There are a number of issues relating to the use of child restraint systems in motor vehicles including child seats that are not used correctly or are inappropriate for the weight and height of the child. CIREN data aids in identifying problems associated with the incorrect or inappropriate use of child restraint systems so that child passenger safety recommendations can be revised and new technologies developed.

Federal Motor Vehicle Safety Standard (FMVSS) 213 sets minimum performance standards that all child restraints must meet. FMVSS 213 is currently being updated to reflect modern vehicle designs, new child restraint systems, and real-world crash scenarios. CIREN is capable of monitoring the effectiveness of FMVSS 213 as it exists now and as better performance standards are implemented.

A. Shield Boosters

Shield booster seats were originally designed for use in vehicles with lap belts in the rear seating position and were certified for use in children 30-60 pounds. In 1996, FMVSS 213 was updated so that child restraints marketed for use in children over 40-pounds had to meet crash test standards using a 6-year old, 47-pound dummy rather than the 3-year old, 33-pound dummy previously used. This important change resulted in the de-certification of shield boosters for children over 40 pounds. However, current research indicates that shield boosters comprise 50-68% of all boosters in circulation. Although shield booster seats meet FMVSS 213 standards for use with children 30-40 pounds, our real-world crash data indicates that shield boosters are not appropriate for use by these children. Recently, our CIREN center analyzed data to assess the performance of the shield booster seats.

Case Example A. Top Tether Used with Forward-Facing Child Safety Seat

Case A. Occupant & Vehicle Information

— 2-year-old female (33 pounds)
— Left Rear Seating Position
— Safety Seat 5-Point Harness
— Top Tether Anchored Correctly
— 2000 Subaru Outback Limited
— Frontal Impact
— Delta-V of 31.7 mph

Case Seat with Top Tether

Case A. Injury Analysis

— Slight Diastasis Fracture at C2-C3
— Bilateral Shoulder Abrasions
— Injury Severity Score = 5
— Maximum AIS = 2
— Length of Stay = 1 day

No Contact to Seatback

Among our CIREN cases, there were 16 children less than 40-pounds restrained in shield booster seats. Today, all forward-facing child safety seats are certified for use in children up to 40 pounds and provide better protection to children in this weight range. An analysis of CIREN data revealed that when compared to children restrained in forward-facing child safety seats, children in shield booster seats suffered more serious injuries, had longer hospital stays, higher acute care charges, and poorer outcomes. Shield booster cases also had a higher frequency of severe injury to the abdomen/pelvic region and to the thoracic cavity. These findings were presented to physicians at the Pediatric Academic Societies' Meeting and submitted for publication in Pediatrics so that pediatricians can help counsel patients on booster seat selection. Furthermore, our data was presented to NHTSA personnel in hopes that efforts will be made to remove shield booster seats from the market.

B. Infant and Child Car Seats

The frequencies of various types of child restraint misuse have been well documented, but little information exists on the consequences of such misuse. CNMC CIREN has been instrumental in documenting the injuries that result from improper installation of child safety seats. For example, analysis of our car seat cases revealed that incorrectly restrained children experienced a significantly higher mean Injury Severity Score (ISS) and significantly higher medical charges than correctly restrained children. Because child restraint misuse drastically increases the risk of injury to children in crashes, NHTSA has mandated that all new vehicles be designed with the Lower Anchors & Tethers for Children (LATCH) system in the outboard rear seating positions. LATCH is a restraint system designed to work independently of the vehicle seat belt system to simplify child safety seat installation and reduce misuse. Used properly, the system is expected to save up to 50 lives a year and prevent close to 3,000 crash-related injuries. As with any new technology, evaluation is essential and CIREN will play an important part of that process.

Belt-positioning booster seats

As our knowledge on seatbelt syndrome in children has continued to grow, new child passenger safety recommendations have been implemented. Over the past several years, national efforts have been made to increase the use of booster seats among school-aged children. Part of the difficulty in increasing usage stems from the lack of real-world

Case Example B. High-Back Booster

Case B. Occupant & Vehicle Information

— 6-year old female (48 pounds)
— Left Rear Seating Position
— High-Back Booster
— Booster used with 3-Point Belt
— 2000 Pontiac Bonneville
— Frontal Impact
— Delta V of 28 mph

Case B. Injury Analysis

— Two Right Rib Fractures
— Grade I Liver Laceration
— Thigh Laceration
— Injury Severity Score = 9
— Maximum AIS = 2

Shoulder Contusion

Thigh Laceration

Rib Fracrures

Case Example C. Seatbelt

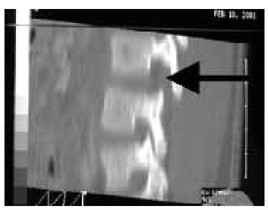
Case C. Occupant & Vehicle Information

— 7-year old female (49 pounds)
— Left Rear Seating Position
— 3-Point Belt
— Shoulder belt positioned under arm
— 1999 Dodge Avenger
— Frontal Impact
— Delta V of 30 mph


Case C. Injury Analysis

— L3-L4 Lumbar Spine Distraction
— Avulsed Lumbar Nerve Roots
— Two Large Colon Perforations
— Paraplegia
— Injury Severity Score = 26
— Maximum AIS = 5

Post-Operative Incision



L3-L4 Distraction

data on booster seat effectiveness, but as usage increases, CIREN will be an important resource in evaluating their performance. Above is a comparison of the booster seat case (Case B) with a similarly sized child in a seatbelt (Case C). In the near future, we hope to provide more definitive feedback regarding booster seat effectiveness.

Vehicle Safety

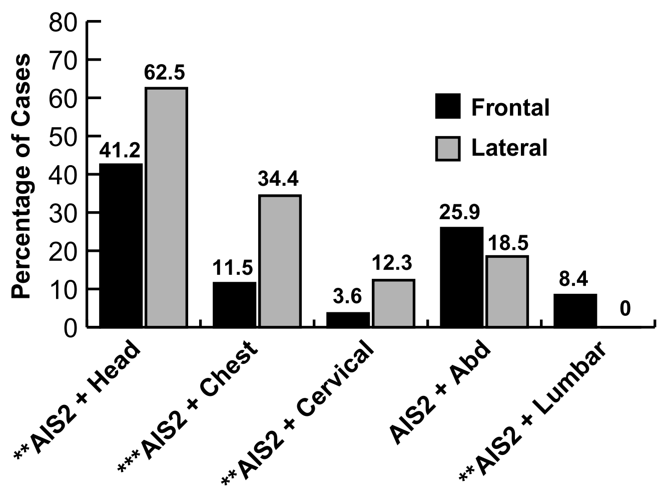
Side impact syndrome

Side impact collisions cause a significant percentage of deaths to children. We recently identified a new distinct pattern of injury for restrained children involved in side impact crashes. This information can also provide a useful tool in the differential diagnosis of children injured in motor vehicle collisions. Information on the direction and severity of crash, restraint use, and seating position can supplement vital signs and physical findings when determining the need for further diagnostic testing. Furthermore, identifying injury patterns to children involved in side impact collisions can help improve vehicle safety. In the past, the interior padding of the automobile instrument panel and other surfaces were designed with the adult passenger in mind. While children's shorter stature may lessen the likelihood of vehicle contact in frontal collisions, it may put them at increased risk of certain types of intrusion-related injury from side impact collisions.

The Transportation Recall, Enhancement, Accountability, and Documentation (TREAD) Act requires NHTSA to upgrade Federal Motor Vehicle Safety Standard No. 213, Child Restraint Systems, to include side and rear-end impacts. NHTSA recently released an Advanced Notice of Proposed Rulemaking (ANPRM) to address requirements for side impact collisions. According to NHTSA, one of the severe challenges in modifying FMVSS 213 to address side impact collisions is that little or no data exists describing the medical nature of child injuries in side impact crashes. CIREN has an important role in elucidating some of the injury mechanisms associated with side impact collisions. Preliminary analysis of approximately 65 CIREN side impact cases describes the specific patterns of injury for restrained children – *side impact syndrome*:

- Children in side impact crashes experienced higher overall morbidity than children in frontal crashes, despite a lower mean total delta V.
- Lateral impact crashes resulted in a higher frequency of intrusion/intrusion-related injury (p<. 05).
- Children in side impact crashes are more than three times as likely to have an ISS>15 than children in frontal crashes. Furthermore, side impact collisions result in greater risk of sustaining an AIS2+ head injury, AIS2+ cervical spine injury, and AIS2+ chest injury.

Figure 1. Injured Body Region by Direction of Impact.



All frontal cases (n=166) compared to all lateral cases (n=65). *p<.05; **p<.01, ***p<.001.

In addition to FMVSS 213, NHTSA has made changes to FMVSS 214, side impact collisions, that require reinforcement of side door panels and other protective measures. Side impact airbags are also becoming more prevalent because they can provide significant supplemental safety benefits to adults. However, children who are seated in close proximity to a side air bag may be at risk of serious or fatal injury, especially if the child's head, neck, or chest is in close proximity to the air bag at the time of deployment. In the coming years, CIREN will have an important role in demonstrating the effectiveness of the new side-impact safety standards and advanced technologies like side impact airbags.

Biomechanical Research

Data on pediatric injury tolerance is scarce since practical and moral constraints make research using pediatric cadavers unfeasible. Measures of head excursion and head injury criteria values are available for pediatric dummies restrained in safety seats, but due to lack of information on pediatric injury tolerances, considerable uncertainty exists regarding how these measurements relate to injury risk.

The CNMC CIREN center funded a child restraint misuse research project at the University of Virginia Automotive Safety Laboratory. Sled tests and computer modeling were used to explore all combinations of correct/incorrect and appropriate/inappropriate seating conditions in 4 different aged dummies (6 month old, 12 month old, 3-year old, 6-year old). A total of 38 sled tests were performed, and multi-body models (MADYMO) of 3 dummies in more than 10 restraint conditions were constructed.

The parametric studies in this project allowed for joint stiffness to be varied in the models to show the effect on kinematics, forces, and moments. This is important because there is a lack of constitutive data for children, particularly joint stiffness, which influences dummy designs. For example, results from this project indicate that the Hybrid III 6-year old dummy has a non-biofidelic thorax which causes high loads in the dummy's neck (2002 AAAM paper). A submitted paper (2003 SAE) studied the effect of modern restraint countermeasures (force limiting belt, active pretensioners) on the 6-year old child in a booster seat. The sled tests allowed for comparison between belt and LATCH restrained child seats. Additionally, data on the 6-year old dummy from these tests was used in comments to NHTSA on their proposed changes to federal regulations. Occupant and restraint positions (incorrect usage) demonstrated which positions place the child at the most risk of injury. The kinematics identified in the sled tests and the subsequent computer models are being used to improve understanding of the biomechanics of injury among CIREN cases since the models allow for different restraint conditions to be studied.

New Triage, Transport, & Treatment Tools

CIREN has greatly increased our knowledge of injury patterns to restrained children in crashes. In the foreseeable future, we anticipate that these findings will be incorporated into Automatic Crash Notification systems so that injured occupants can be triaged more effectively and transported to a trauma center in a more timely fashion. Child fatalities due to airbag deployment have been well documented. Recently, automobile manufacturers have begun utilizing a sensor technology that can monitor the size and positioning of riders inside vehicles. The systems are able to read the pressure pattern and weight distribution of a person or object to determine if a child seat is placed in the front passenger seat. If so, the front-passenger frontal airbag will automatically turn off and not deploy during a crash. Using a collection of strategically located sensors, these systems can automatically call for help if the vehicle is involved in a moderate to severe frontal, rear or side-impact crash, regardless of air bag deployment. We hope that in the future, valuable findings from CIREN will be incorporated into these notification systems. For example, the system would provide crash severity information to 911 centers such as impact direction, delta V, airbag deployment, child use of seatbelt, child seat anchored to LATCH system, etc., helping to quickly determine the appropriate combination of emergency personnel, equipment and medical facilities needed. This technology is especially promising in many rural areas, where there are fewer motorists to report crashes and less access to state-of-the-art urban trauma centers to treat crash victims.

Pediatric Outcomes

Long-term consequences of motor-vehicle crashes not only affect physical functioning but psychosocial functioning as well. Long-term outcome research is vital in assessing the impact of the injury on children and their families. Although CIREN obtains detailed information regarding a child's condition at discharge, no long-term quality of life information has been collected in the past. In the near future, CNMC will begin assessing quality of life for all CIREN cases at baseline and at 6-months post-discharge. The questionnaire is designed to provide reliable information about the everyday functioning and well-being of children. It asks questions about the child's physical wellness, his/her feelings, behavior, and activities at school and with family and friends. CNMC is about to implement long-term outcomes research into the CIREN data collection process. Interview with both child and parent will be conducted at baseline to assess pre-crash functioning and again at 6-months and 1-year post-discharge to assess the post-crash functioning. Questions will assess functioning in each of the following areas:

> Physical Functioning, Social Functioning, Psychosocial Functioning, Emotional Functioning, and School Functioning.

Publications 2001–2002

Sherwood CP, Shaw CG, van Rooij L, Kent RW, Gupta PK, Orzechowski KM. Prediction of Cervical Spine Injury Risk for the 6 Year Old Child in Frontal Crashes. Association for the Advancement of Automotive Medicine

Platform /Poster Presentations 2001–2002

Orzechowski KM, Edgerton EA, McLauglin PM, Eichelberger MR. Pediatric Motor Vehicle Crash Injuries Associated with Restraint Misuse. Third National Congress on Childhood Emergencies. Dallas, TX, April 2002

Orzechowski KM, Edgerton EA, McLauglin PM, Eichelberger MR. CIREN: A Multidisciplinary Approach to the Prevention of Motor Vehicle Crash Injuries. Third National Congress on Childhood Emergencies. Dallas, TX, April 2002

Orzechowski KM, Edgerton EA, Eichelberger MR. Injury Trends Among Improperly Restrained Booster Seat Age Children Involved in Motor Vehicle Crashes. American Academy of Pediatrics 2001 National Conference and Exhibition, San Francisco, CA, October 2001

Literature Cited

i Durbin DK, Kallan MJ, Winston FK. Trends in Booster Seat Use Among Young Children in Crashes. Pediatrics. 2001, December: 108 (6): E109.

ii Advanced Notice of Proposed Rulemaking (ANPRM) To Add A Side Impact Test to FMVSS No. 213 Washington, DC: Office of Regulatory Analysis and Evaluation Plans and Policy, National Highway Traffic Safety Administration, U.S. Department of Transportation, February 2002